



LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

UCRL-JC-152377

Neutron Scintillators for Downscattered Neutron Imaging

*M. J. Moran, J. Koch, C. A. Barrera, E. C.
Morse*

August 25, 2003

2003 Third International Conference on Inertial Fusion
Sciences and Applications, Monterey, CA
September 7-12, 2003

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

Neutron Scintillators for Downscattered Neutron Imaging

Michael J. Moran and Jeffrey Koch,
Lawrence Livermore National Laboratory,
University of California,
Livermore, CA 94550

Carlos A. Barrera, and Edward C Morse
Department of Nuclear Engineering
University of California, Berkeley,
Berkeley, CA 94704

ABSTRACT

Images of neutron emission from Inertial Confinement Fusion (ICF) (D,T) targets reveal the internal structure of the target during the fusion burn. 14-MeV neutrons provide images which show the size and shape of the region where (D,T) fusion is most intense. Images based on "downscattered" neutrons with energies from 5 to 10 MeV emphasize the distribution of deuterium and tritium fuel within the compressed target. The downscattered images are difficult to record because the lower energy neutrons are detected with less efficiency than the much more intense pulse of 14-MeV neutrons which precedes them at the detector. The success of downscattered neutron imaging will depend on the scintillation decay times and the sensitivities to lower-energy neutrons of the scintillator materials that are used in the detectors. A time-correlated photon counting system measured the decay of neutron-induced scintillation for times as long as several hundred ns. Accelerators at the University of California, Berkeley, and the Lawrence Livermore National Laboratory provided stable 14-MeV neutron sources for the measurements. Measurements of scintillator decay characteristics indicate that some commercially available scintillators should be suitable for recording both 14-MeV and downscattered neutron images of compressed ICF targets.

INTRODUCTION

Commercially available scintillators are classified according to their state (liquid, single crystals, gases or solid solutions), active ingredient, and responses to specific kinds of radiation. Many scintillators produce emissions having time a dependence which, after a rapid rise to the emission peak, can be represented as a sum of exponential decays.[1] Scintillator manufacturers often specify both the rise and decay times, with the latter usually referring to the "fast" component of the decay.

Neutron images can be recorded by using a neutron scintillator to convert a neutron distribution to a corresponding spatial distribution of scintillation light which then can be recorded as an image by a conventional camera. Organic scintillators have served this purpose in the past, as their fast time response and relatively high sensitivity have made possible the recording of neutron images in ICF experiments. A study of the feasibility of recording 14-MeV and downscattered neutron images in ICF experiments at the NIF has produced experimental requirements which may not be satisfied by the organic scintillators which have been used previously. In particular, submillimeter resolution and rapid scintillation decay will be required in order to achieve the desired spatial resolution and to record weak downscattered neutron images after a much brighter 14-MeV image.

This paper describes preliminary results from the measurement of the decay characteristics of scintillation produced by 14-MeV neutrons in three different commercial scintillators, Bicron BC-422, BC-422Q, and BC-509. BC-422 is a conventional plastic scintillator, BC-422Q is doped to a 1% concentration with a quenching agent, and BC-509 is a nonhydrogenous liquid scintillator (hexafluorobenzene). The varieties of BC-422 have been used previously for neutron imaging, as they offer good neutron sensitivity and fast decay times. BC-509 is a fast scintillator which has not been used previously for neutron imaging, and it may offer advantages with respect to spatial resolution (because of the absence of long-range proton recoils).

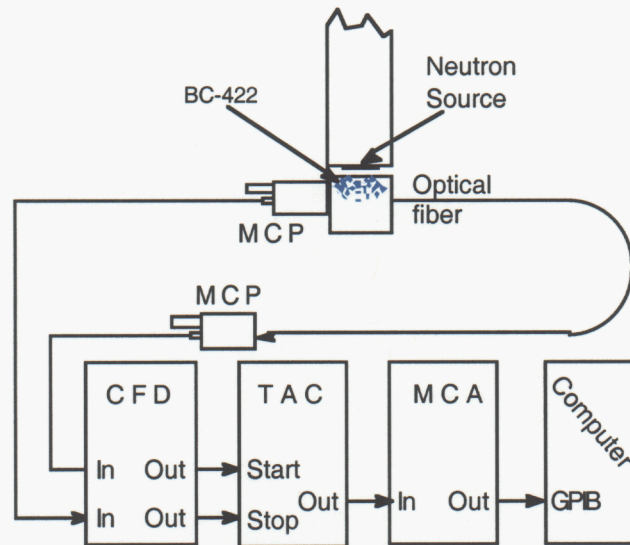


Figure 1 Experimental set up

EXPERIMENT

In the present experiments, a Time Correlated Photon Counting (TCPC) measured the decay scintillation light produced by 14-MeV neutrons in samples of BC-422 and BC-509 scintillators. TCPC is a well established technique in organic chemistry and physics which is used to measure phosphorescence/fluorescence lifetimes.[2] The basis of TCPC is to sample single photon emission times with a low-efficiency detector, relative to a consistent time fiducial which signals the occurrence of an event of interest. The accumulation of single-photon emission times produces a temporal probability distribution of photon emission by the scintillator.

Figure 1 illustrates the experimental set-up. The scintillator sample is placed in a light tight housing. Neutrons in the scintillator produce in excess of 10^3 photons for each interaction with a 14-MeV neutron. The (D,T) neutrons are produced by either a Texas Nuclear generator, or a Kaman Sciences A-1254 Neutron Generator which produced approximately 10^6 neutrons/sec. One PMT (Burle 8850) is close-coupled to the scintillator and produces an electrical time marker for each event in the scintillator. A fused silica fiber optic bundle is mounted in a position where it intercepts a small fraction of light from the scintillator. The optical fiber collects approximately one photon per 10^4 neutron interactions. The single photons are conducted by the optical fiber to a second PMT (Hamamatsu H5783) which is located approximately four meters away. The anode signal of the H5783 is then amplified and fed to a carefully tuned constant-fraction discriminator (CFD). The anode signal of the 8850 is large enough to be connected directly to a constant fraction discriminator CFD; the H5783 signal is amplified before being connected to a second CFD. The CFDs produce the START and STOP pulses for the Time-to-amplitude Converter (TAC), with a time window of 1000 ns. The output of the TAC is recorded in a computer Multi-Channel Analyzer (MCA).

Figure 2 shows the measured decay for BC-422. The data have not been corrected for the finite time response of the recording system. The time response is fast enough (≈ 1.5 ns) that the long-term decays results should be accurate, although the prompt decay characteristics may be slightly distorted. For example, the prompt decay time of 2 ns given in Fig. 1 is slightly longer than the 1.4 ns which Bicron specifies for this scintillator.[3] Data were collected for sufficient time to accumulate roughly 10^5 counts/channel at the peak, and to have sufficient data for measuring the decay rate for times in excess of 500 ns. The data have been fitted with three exponential decay terms: a prompt decay, a long-term decay, and an intermediate decay between those two regions. Data for the BC-422Q sample were indistinguishable from that shown in Fig. 2. This is not surprising, as the modest (1%) level of quenching has its greatest effect on the prompt response of the scintillator, which the present system is not capable of resolving clearly.

Figure 3 shows the measured decay for BC-509. Once again, the prompt decay characteristics may be slightly distorted. For example, the prompt decay time of 2 ns given in Fig. 1 is slightly longer than the 3.1 ns which Bicron specifies for this scintillator.[3] Data were collected for sufficient time to accumulate roughly 10^5 counts/channel at the peak, and to have sufficient data for measuring the decay rate for times in excess of 500 ns. As in Fig. 2, the data have been fitted with prompt, long-term, and intermediate exponential decay terms.

RESULTS

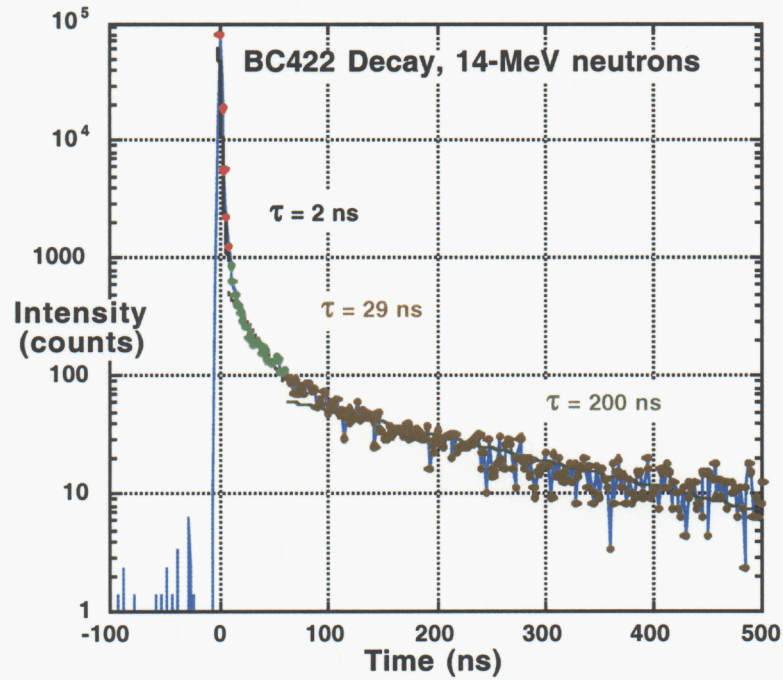


Figure 2 BC-422 Scintillation Decay

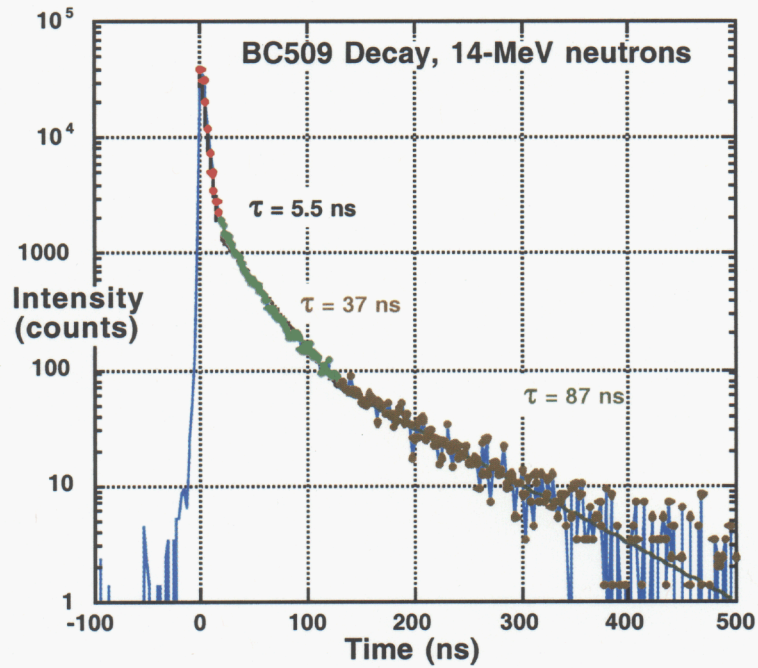


Figure 3 BC-509 Scintillation decay

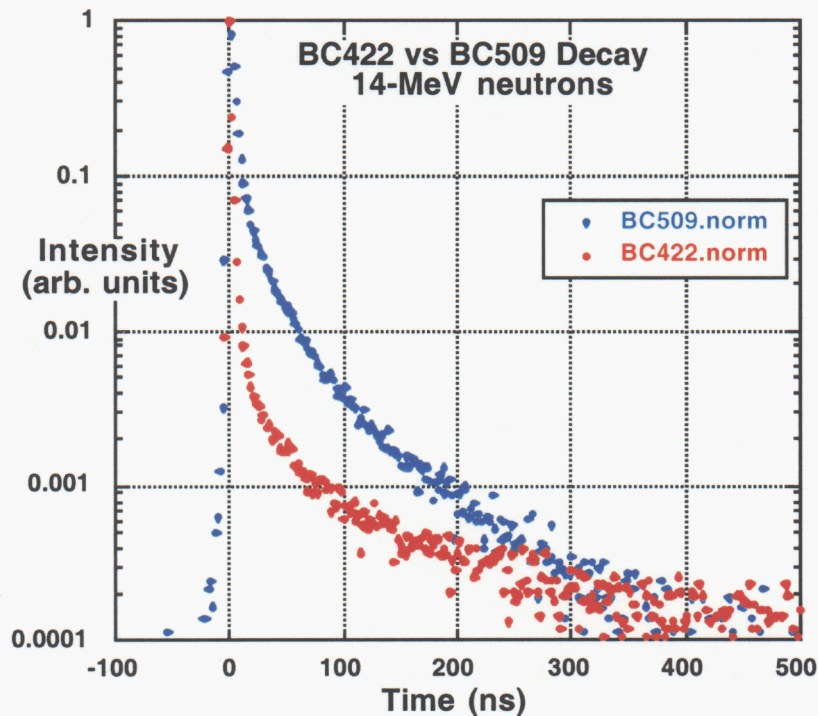


Figure 4 BC-422 vs. BC-509 Scintillation Decay Comparison

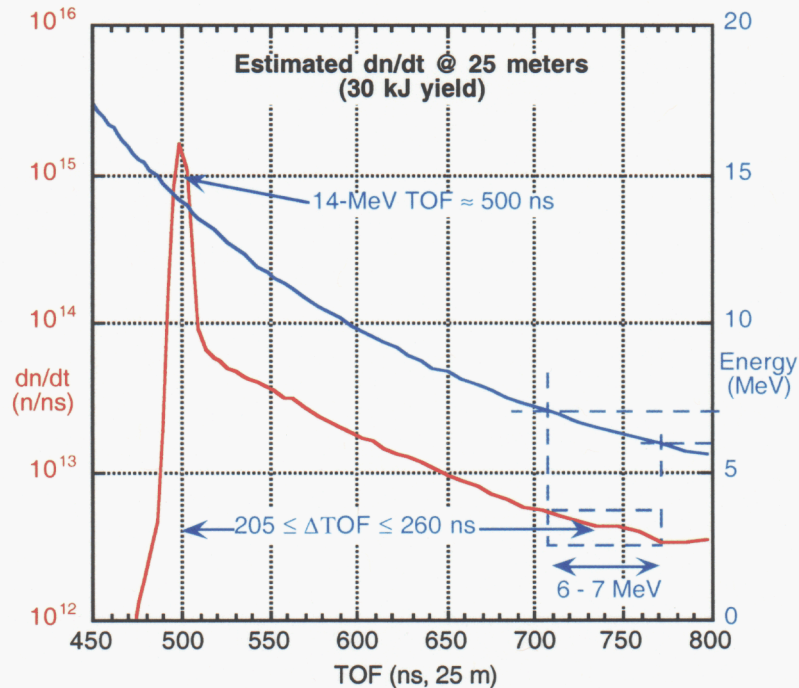
Figure 4 compares the measured scintillation decays for BC-422 and BC-509. The data have been normalized to a value of 1 at $t=0$. The comparison displays significant differences in the decay curves of the two scintillators. The prompt decay of the BC-422 is much faster than that of BC-509, as expected. However, the late time decay of the BC-509 is more rapid than that for BC-422, so that the two emission histories become comparable at about 300 ns after the scintillations event.

DISCUSSION

The measured decay times shown above are consistent with manufacturer's specifications and with previously reported results.[4,5] The present results, however, used 14-MeV neutrons as the radiation source, and emphasize the late-time behavior of the scintillators. The prompt decay curves shown in Figure 4 display the expected differences in prompt decay times for the two scintillators, and also show significant differences in their late-time decay characteristics. Although BC-509 has slower prompt decay rates, the corresponding late-time decay is faster than that for BC-422. The net effect is that the scintillation intensity is approximately equal for the two scintillators at a time of about 300 ns after a scintillations event. The BC-509 shows very little evidence of scintillation for times greater than 300 ns after the scintillation event, while BC-422 continues to produce scintillation at low levels for times as long as 700 or 800 ns.

The late time behavior shows that both scintillators decay by more than a factor of 1000 at a time of 250 ns after the scintillation event. This rate of decay is significant, because it suggests that downscattered neutron imaging might be feasible in NIF ICF experiments. Figure 5 shows the time-dependent neutron flux (red) that would be expected on a detector at 25 meters from an ICF capsule which produced a fusion yield of 30 kJ.[6] The plot also indicates the neutron energies that correspond to arrival times at the detector. For

downscattered neutron energies of 6-7 MeV, the flight times are about 225 ns longer than that for the prompt 14-MeV neutrons. The downscattered neutron fluxes are about 300 time less than those for the 14-MeV neutrons. Thus, in order for the downscattered image to be detectable, the "flash" from the earlier 14-MeV neutrons must have decayed by a factor of 300, or more. Since the measured decays in Fig. 4 at a level which is down by a factor of more than 1000 after the scintillation event, it appears that both scintillators are viable candidates for downscattered neutron imaging in NIF ICF experiments.



CONCLUSIONS

The present measurements of scintillation decay show that both BC-422 and BC-509 are possible candidates for performing downscattered neutron imaging measurements in ICF experiments at the NIF. The decay rates appear to be sufficiently rapid to allow recording a downscattered image in the presence of a faint residual image from the earlier 14-MeV "flash". The ultimate choice of a scintillator will depend, as well, on characteristics such as the energy dependence of the neutron sensitivity and spatial resolution characteristics. Measurements of the energy dependence of neutron sensitivity are planned for the near future, and prototype designs for imaging detectors are being developed. This ongoing work should make it possible to select at least one scintillator and detector design that will be appropriate for recording the desired downscattered neutron images. This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

REFERENCES

1. Knoll, G. F. Radiation Detection and Measurement, Third Edition Chapter 8. John Wiley & Sons, New York 2000
2. O'Connor, D. V. and Phillips, D. Time Correlated Single Photon Counting Academic Press, New York 1984.
3. Bicron, 12345 Kinsman Road, Newbury, Ohio, USA
4. Flournoy, J. M. Radiat. Phys. Chem. Vol. 41 No. 2 pp. 389-394 1993
5. Lyons, P. B. et al. IEEE Transactions on nuclear Science, Vol. NS-24, No. 1, pp. 177-181 February 1977
6. M.J. Moran, Haan, S.W., Hatchett, S.P., Izumi, N., Koch, J.A., Lerche, R.A., and Phillips, T.W., Rev. of Scient. Inst., Vol. 74, p. 1701 (2003).